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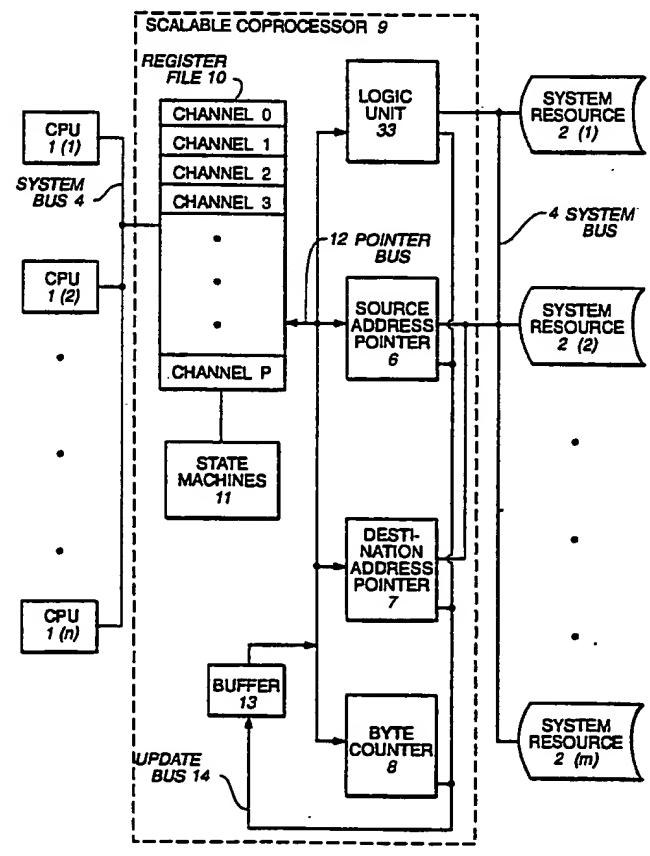
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(54) Title: SCALABLE COPROCESSOR

(57) Abstract

In a computing system, a scalable coprocessor (9) for enhancing communications between a set of central processing units (CPUs) (1) and a set of system resources (2). Scalable coprocessor (9) comprises a single register file (10) compartmentalized into at least two bins, each bin corresponding to a virtual coprocessor channel. Coupled to the register file (10) is a single actual coprocessor (6, 7, 8, 13, 33) for performing operations on the system resources (2). The number of virtual channels can be increased arbitrarily without the need to increase the number of actual channel hardware elements. A set of programmable state machines (11) grants operational authority to the virtual channels in the order desired and for the durations desired. Embodiments of the present invention include a fly-by DMA controller (23), an RAID coprocessor (29), and a striping coprocessor (23).



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D E S C R I P T I O N

Title: SCALABLE COPROCESSOR

5 Technical Field

This invention pertains to the field of computing systems, and in particular to techniques for improving the communications between central processing units and system resources such as input/output controllers and memory.

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Background Art

Figure 1 illustrates the conventional method by which central processing units (CPUs) communicate with system resources 2. The computer system comprises a set of m system resources 2, which can include memory and input/output controllers that are in turn coupled to input/output devices. The system comprises at least one CPU 1 for performing computational tasks, running stored programs, and communicating with system resources 2. Figure 1 illustrates a set of n CPUs 1, all of which are coupled to each other via a system bus 4, typically comprising a set of parallel data lines and a set of parallel address lines. System bus 4, for example, might have 32 parallel data lines and 32 parallel address lines. Using binary arithmetic, this is enough to address 4 Gigabytes of data at random. A bus master 34 is coupled to bus 4 and regulates access thereto.

A DMA controller 3 is associated with each system resource 2. All of the DMA controllers 3 are coupled to system

1 bus 4. On each DMA controller 3 is typically a bus arbiter 5,
a source address pointer 6, a destination address pointer 7,
and a byte counter 8. Bus arbiter 5 is a set of logic that is
duplicated on all of the other DMA controllers 3. Bus arbiter
5 stores priority information associated with that system
resource 2 and indicates to bus master 34 that one of the CPUs
1 wishes to activate the associated system resource 2. Bus
master 34 then determines which of the DMA controllers 3 will
be given authorization to become operational. Only one DMA
10 controller 3 can be operational at any one time.

The way that a CPU 1 communicates with a system
resource 2 is for CPU 1 to place, typically, three pieces of
information into the associated DMA controller 3: the source
address (the address where the data that are the subject of the
15 communication are to be found) is stored in source address
pointer 6; the address of the destination (location where the
data are to be sent) is stored in address pointer 7; and the
number of bytes desired to be moved is stored in byte counter
8. During the operational period, byte counter 8 decrements
20 once during each processing (clock) cycle until the count
stored therewithin reaches zero, at which point it is known
that all of the data have been moved. If CPU 1 wishes to
perform operations such as arithmetic, logic, or shift
operations on the data in addition to simply moving them, this
25 task can be performed by CPU 1 during the operational cycle.

As will be seen, the present invention offers a much
more efficient means for handling communications with the
system resources 2.

1 "RAID Coprocessor", a data sheet by Extended Systems
 (date unknown), describes a device that, as does XOR pipeline
 30 of the present invention, frees a CPU from parity
 calculations in a RAID environment. However, this device can
5 process only one block of data at a time, whereas the present
 invention can process multiple blocks of data simultaneously.

Disclosure of Invention

The present invention is a computer system comprising
10 at least one central processing unit (CPU) (1) capable of
 performing operations on data stored within a set of system
 resources (2). A scalable coprocessor (9) is coupled to the
 CPUs (1) and the system resources (2) via a system bus (4).
Within the scalable coprocessor (9) and coupled to the CPUs (1)
15 is a single register file (10) that is compartmentalized into
 at least two bins, each bin corresponding to a virtual
 coprocessor channel. Coupled to the register file (10) is a
 single actual coprocessor (6, 7, 8, 13, 33) for performing
 operations on the system resources (2). Coupled to the
 register file (10) is a means (11) for apportioning the
20 operational cycles of the actual coprocessor among the set of
 virtual coprocessor channels.

The present invention offers the following major
advantages over the prior art:

- 25 1. The number of virtual channels can be increased
 (scaled) without the need to increase the number of actual
 channel hardware elements (such as items 5, 6, 7 and 8 of the
 prior art), since there is but one scalable coprocessor (9).

- 1 2. Fewer routing resources means consistent and high-speed routing across all virtual channels and higher system clock speeds.
- 5 3. More efficient use is made of the system bus (4), because the virtual channels operate in a time division multiplex mode, with fairness built in.
- 10 4. The means (11) for arbitrating which virtual channels gain operational access and for how long is programmable.
- 15 5. Dynamic updating of the pointer memory array (register file 10) by the host CPUs (1) without any unnecessary timing restrictions.
- 20 6. A more efficient way of performing scatter/gather operations (read and writes, respectively, when the data are fragmented among many blocks), because scatter/gather is performed in parallel rather than sequentially as has been conventional.

Brief Description of the Drawings

20 These and other more detailed and specific objects and features of the present invention are more fully disclosed in the following specification, reference being had to the accompanying drawings, in which:

25 Figure 1 is a block diagram of the conventional prior art technique of communicating among CPUs 1 and system resources 2;

Figure 2 is a block diagram of scalable coprocessor 9 of the present invention;

1 Figure 3 is a block diagram of state machines 11 of
scalable coprocessor 9 of the present invention;

Figure 4 is a sketch of amplitude versus time for gas
pedal signal 15 of the present invention;

5 Figure 5 is a block diagram of a fly-by DMA controller
23 embodiment of the present invention; and

Figure 6 is a block diagram of a RAID coprocessor 29
embodiment of the present invention.

10 Best Mode for Carrying Out The Invention

Figure 2 is a block diagram of a general embodiment of
scalable coprocessor 9 of the present invention. The
environment is a computer system which comprises at least one
central processing unit (CPU) 1. Each CPU 1 can be any active
15 processing element capable of performing an operation on a set
of system resources 2. n CPUs 1 are illustrated in Figure 2.
CPUs 1 are all coupled together via the same system bus 4. For
example, system bus 4 may have 32 parallel data lines and 32
parallel address lines. This is enough to address four
20 Gigabytes of data at random.

By using this invention, each CPU 1 can submit
multiple I/O requests simultaneously. For example, a CPU 1 can
be a file server that asks for hundreds of files simultaneously.

System resources 2 are likewise coupled together via
25 the same system bus 4. Only one operation can be performed on
system bus 4 at any given time. System resources 2 comprise,
typically, memory and input/output controllers that are in turn

1 coupled to input/output devices such as disk drives, tape drives, CD ROMs, Bernoulli boxes, etc.

There is needed only one scalable coprocessor 9 in the computer system. This eliminates the duplication of devices
5 and data paths that was common in the prior art, such as that illustrated in Figure 1. Coprocessor 9 communicates with system resources 2 at speeds approaching memory bandwidth, e.g., 66 MBps in embodiments that have been built, rather than at slower CPU 1 bandwidths.

10 Scalable coprocessor 9 is coupled to CPUs 1 via system bus 4 and comprises register file 10, a set of state machines 11, and an actual coprocessor comprising at least one address pointer (e.g., source address pointer 6 and destination address pointer 7), byte counter 8, buffer 13, and (optionally) logic unit 33. Pointers 6 and 7 are storage devices such as registers or programmable counters.

Register file 10 is a storage device such as a random access memory (RAM) that has been preselectedly compartmentalized into an arbitrary number of $p+1$ storage areas
20 or bins corresponding to the number of virtual coprocessor channels that the user of coprocessor 9 has decided to set up in advance. For example, $p+1$ may correspond to the number of blocks of data that are known to be present in the computer system. Each bin or channel stores at least three pieces of information: the beginning address of the data that are to be used as the source for an operation, the beginning address of the desired destination for the data after the operation has been performed, and the size of the data that are the subject

1 of the operation. Additionally, information can be stored in
the channel indicating the type of arithmetic, logic, or shift
operation desired to be performed on the data.

The set of state machines 11 determines which channels
5 are allowed to become operational in which order and for how
long, based upon a programmable arbitration scheme stored
within state machines 11. When a given channel is allowed to
become operational, the stored source address from that channel
is placed into source address pointer 6 via pointer bus 12, the
10 destination address is placed into destination address pointer
7 via pointer bus 12, and the byte count is placed into byte
counter 8 via pointer bus 12. Additionally, the stored
arithmetic, logic, or shift instructions, if any, are placed
into optional logic unit 33 over pointer bus 12.

15 As coprocessor 9 is clocked through its normal
operational cycles by a conventional clock (not shown), e.g.,
at the rate of 66 Megahertz, the desired operations are
performed. The source data are addressed by means of source
address pointer 6 placing the source address over system bus
20 4. The destination address is similarly accessed by pointer 7,
again using system bus 4. If it is desired to perform an
arithmetic, logic, or shift operation on the data and not just
simply move them, logic unit 33 is invoked. Finally, byte
counter 8 is decremented once per cycle.

25 Typically, state machines 11 allow each channel to
perform a finite number of operations (corresponding to a given
finite number of clock cycles) per operational authorization.
128 cycles is a typical number. This may or may not be enough

1 cycles to permit the channel to complete its assigned tasks.
If it is enough, byte counter 8 decrements to 0 and state
machines 11 pass control to the next channel. If it is not a
sufficient number of cycles, the status of items 6, 7, 8, and
5 33 are passed over update bus 14 via buffer 13 and back to
register file 10 over pointer bus 12, so that the next time the
particular channel is granted operational authorization, it can
resume where it was interrupted. Buffer 13 is needed because
one of the CPUs 1 may be trying to initialize another channel
10 within register file 10 at the same time that the updated
information is being sent back to register file 10 over update
bus 14. Thus, buffer 13 prevents collisions of inbound and
outbound information.

Figure 3 illustrates in more detail the set of state
15 machines 11. The first state machine is a programmable arbiter
20, which may comprise random access memory plus associated
logic devices. Arbiter 20 stores the programmable scheme for
arbitrating which channels are given operational access and for
how long. The programming scheme may entail the use of gate
20 arrays, EEPROMs, fuses/anti-fuses, etc. The arbitration scheme
may be any one of a number of techniques such as round robin
(cycling through the channels in order and then repeating at
the zeroeth channel), priority (giving authorization only to
channels which are flagged with certain priority bytes or
25 giving flagged channels a greater number of operational cycles
than channels not flagged), etc.

A set of channel lines CH is input into programmable
arbiter 20. These lines can originate from register file 10

1 (as illustrated) or from system resources 2. The purpose of
these lines is to indicate whether the associated channels are
active (desirous of performing operations on system resources
2) or not. The output of arbiter 20 is a line conveying the
5 number of the channel which is being granted operational access
at any given time. This signal is fed to channel initialize
and update module 21. One of the outputs of module 21 is a
register file address index, which informs register file 10
which channel is being given operational authorization. The
10 length of this index is variable, depending upon the number of
channels. For example, if there are eight channels, this index
requires three bits.

The other output of module 21 is a channel ready
signal. This signal is fed to gas pedal module 22. The
15 composite output of gas pedal 22 is a square wave 15, whose
amplitude versus time is illustrated in Figure 4. When gas
pedal signal 15 is high, this indicates the presence of a
throttle (operational) period 18, i.e., one in which operations
on the data are being performed by actual coprocessor 6, 7, 8,
20 33. When gas pedal signal 15 is low, this indicates the
presence of an idle period 19 during which no virtual channel
is allowed to be operational, but rather CPUs 1 rather than
coprocessor 9 are given access to system bus 4. The durations
of the throttle and idle periods 18, 19 are variable and
25 programmable in advance.

The transition between an idle period 19 and a
throttle period 18 is denominated as a wakeup signal 16 and is
passed to arbiter 20, which induces arbiter 20 to perform a new

1 designation of authorized channel. The transition from a
throttle period 18 to an idle period 19 is denominated as a
tired signal 17, and is passed to arbiter 20 (commanding it to
designate no channel as the designated channel). Tired signal
5 17 is also passed to channel initialize and update module 21,
inducing module 21 to instruct items 33, 6, 7, and 8 to send
their status back to register file 10. This information
becomes the beginning status for the next throttle period 18
the next time that particular channel is given operational
10 authorization by state machines 11.

Figure 5 illustrates a specific embodiment of the present invention: a fly-by DMA controller 23. This embodiment of scalable coprocessor 9 is used in conjunction with non-addressable devices such as input/output controllers 15 25. Since these devices are non-addressable, one of the pointers 6, 7, from the general embodiment can be eliminated. Thus, a single input/output address pointer 24 is used to indicate where in memory 26 data to be read from or written to I/O controller 25 are stored. Pointer 24 points to the 20 beginning location in memory 26 where the data are to be read from or written to. A separate request line 28 and acknowledge line 27 connects pointer 24 with each I/O controller 25. A signal is sent by I/O controller 25 over request line 28 to address pointer 24, asking DMA controller 23 to start each byte 25 transfer. Similarly, a signal is sent from pointer 24 over acknowledge line 27 to I/O controller 25 for each byte that is transferred, signaling that system bus 4 is available to perform the read or write operation. Byte counter 8 decrements

1 for each transferred byte. This process continues until the
byte count for the virtual channel becomes zero, at which time
an interrupt is issued to the associated CPU 1 if required.
The data move directly from memory 26 to the I/O controller 25
5 over system bus 4, without going through controller 23. This
is characteristic of a fly-by DMA controller, as opposed to a
flow-through DMA controller.

A second embodiment of the present invention is
illustrated in Figure 6: a RAID (redundant array of
10 inexpensive disks) coprocessor 29. In this application there
are $m-1$ equally sized blocks of memory 26, where $m-1$ is at
least 2. The output is a set of m equally sized blocks of data
that are written to a set of disk controllers 2. The m th block
is a byte-by-byte parity check on the first $m-1$ blocks. This
15 permits fault tolerant processing: if any one block fails,
including the parity block, all of the data can be
reconstructed from the remaining blocks.

In this embodiment, register file 10 contains but a
single destination pointer, because the writing onto the m disk
20 controllers 2 is automatically partitioned equally among the m
controllers 2. Exclusive OR (XOR) pipeline 30 is a special
case of logic unit 33. Every time a source block of data is
read in from a memory 26, an exclusive OR (XOR) is performed
byte by byte, e.g., 8 bits by 8 bits even when the words are 32
25 bits long. After all of the $m-1$ blocks of data have been read
in, XOR pipeline 30 contains the parity block. This is written
to the destination controller 2(m) along with the other $m-1$
blocks of data, which are written to the first $m-1$ controllers

1 2. Pipeline 30 communicates with the memories 26 and disk
 controllers 2 over the data lines subset 31 of system bus 4.
 Similarly, address pointer 24 communicates with memories 26 and
 disk controllers 2 over the address lines subset 32 of system
5 bus 4. The byte count stored in register file 10 is the same
 for each source 26, because each block of input data has the
 same number of bytes. State machines 11 give operational
 authority to the $m-1$ sources 26 sequentially.

A third embodiment of the present invention is a
10 striping coprocessor. In a hardware sense, it is the same chip
 as the fly-by DMA controller 23, illustrated in Figure 5. The
 striping coprocessor 23 takes as inputs the m blocks of data
 that have been written onto the disk controllers 2 by the RAID
 coprocessor 29 and notionally (via software) stripes these
15 blocks of data onto m I/O controllers 25. Striping is an
 intentional scatter, i.e., the data are fragmented into m
 equally sized blocks. The number of stripes and their widths
 are based upon hardware considerations.

Devices illustrated in Figures 5 and 6 have been built
20 using FPGA (field programmable gate array) technology,
 specifically 4000 series architecture of Xilinx Corporation.
Other suitable construction techniques include printed circuit
 boards and ASICs (application specific integrated circuits).

The above description is included to illustrate the
25 operation of the preferred embodiments and is not meant to
 limit the scope of the invention. The scope of the invention
 is to be limited only by the following claims. From the above
 discussion, many variations will be apparent to one skilled in

1 the art that would yet be encompassed by the spirit and scope
of the invention.

What is claimed is:

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C L A I M S

1. A computer system comprising:
 - at least one central processing unit (CPU) capable of
 - 5 performing operations on data stored within a set of system resources; and
 - a scalable coprocessor coupled to the CPUs and to the system resources, said scalable coprocessor comprising:
 - coupled to the CPUs via a system bus, a single
 - 10 register file compartmentalized into at least two bins, each bin corresponding to a virtual coprocessor channel;
 - coupled to the register file and to the system resources, a single actual coprocessor for performing operations on the system resources; and
 - 15 coupled to the register file, means for apportioning the operational time of the actual coprocessor among the set of virtual coprocessor channels.
 2. The computer system of claim 1 wherein the system resources comprise memory and input/output device controllers.
 3. The computer system of claim 1 wherein the number of bins is variable and is preselected.
 - 25 4. The computer system of claim 1 wherein the actual coprocessor comprises means for performing any combination of any arithmetic, logic, and shift operations on multiple blocks of data within the system resources.

1 5. The computer system of claim 1 wherein the apportioning means comprises means for determining the order and duration for which the virtual coprocessor channels are given operational authorization.

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6. The computer system of claim 5 wherein the determining means comprises a programmable throttle which sets the number of operations each virtual channel is allowed to perform during each operational authorization.

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7. The computer system of claim 6 wherein idle periods are interspersed between throttle (operational) periods; and

the system bus is free to be used by the CPUs during
15 the idle periods.

8. The computer system of claim 1 wherein the actual coprocessor is fly-by DMA controller.

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9. The computer system of claim 1 wherein the actual coprocessor is a RAID (redundant array of inexpensive disks) coprocessor.

10. The computer system of claim 1 wherein the actual
25 coprocessor is a striping coprocessor.

11. The computer system of claim 1 wherein the actual coprocessor comprises a byte counter coupled to the register

1 file via a pointer bus, at least one address pointer coupled to
the register file via the pointer bus, and a buffer coupled to
the address pointer(s), the byte counter, and the pointer bus.

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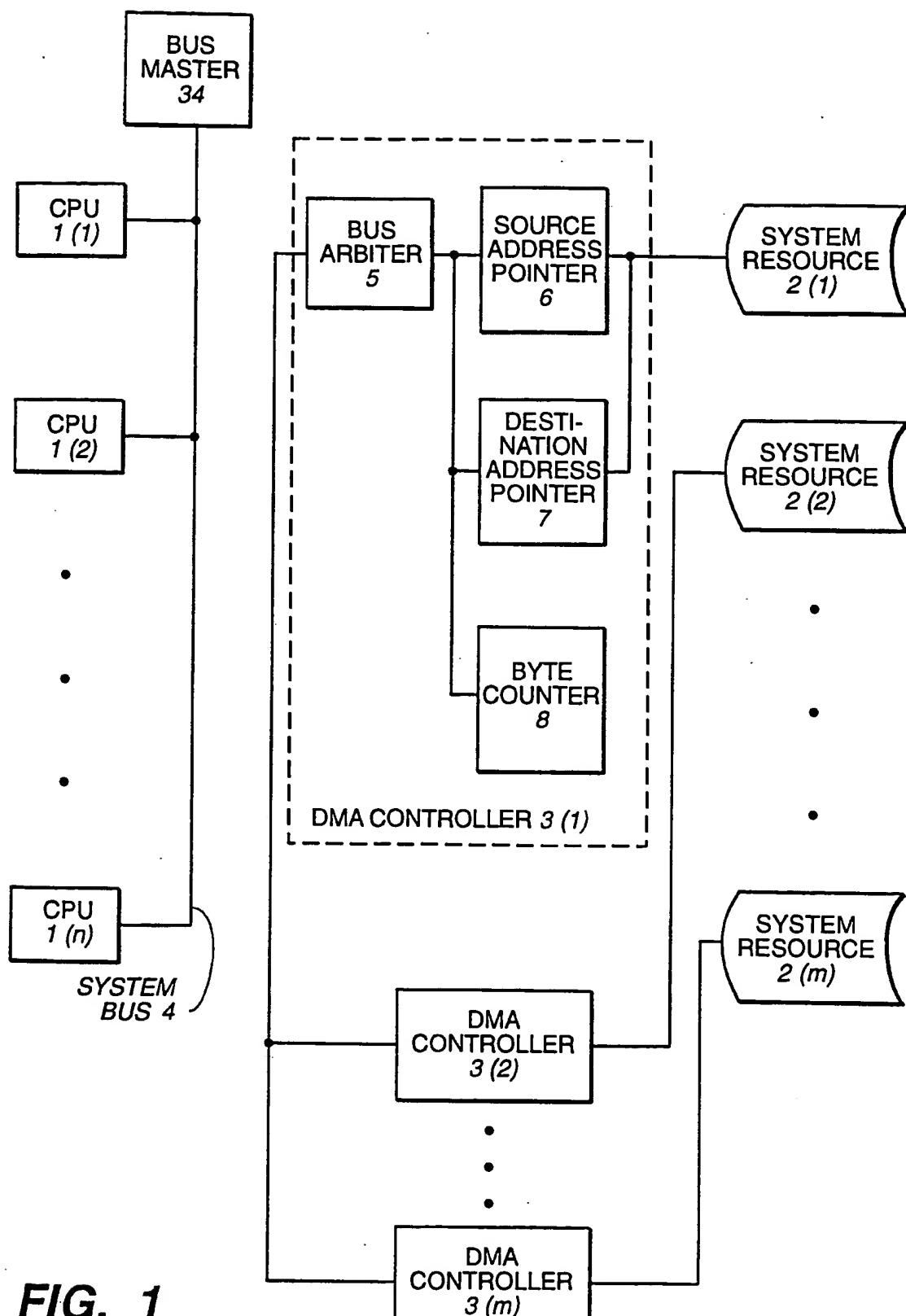


FIG._1
(PRIOR ART)

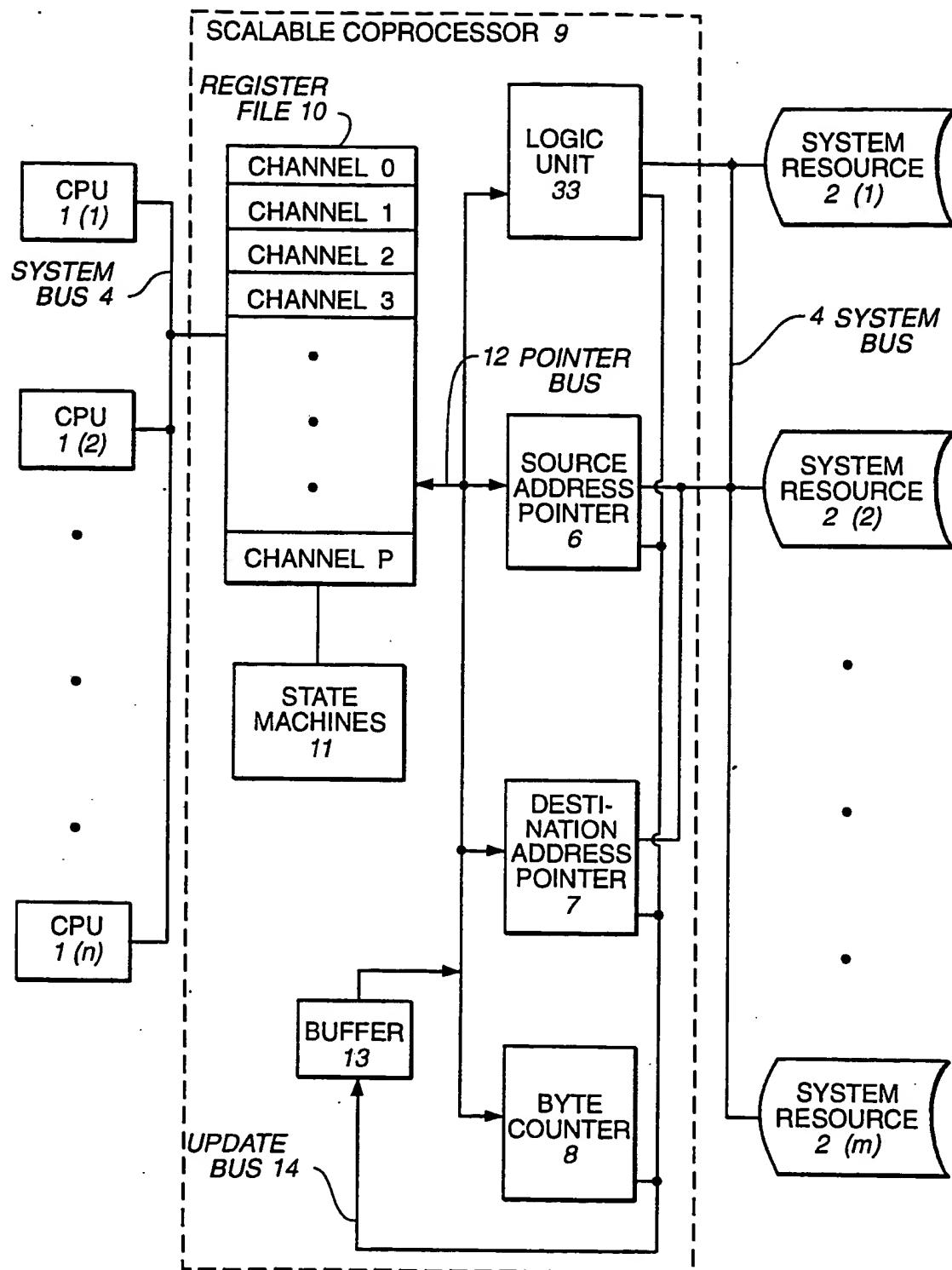
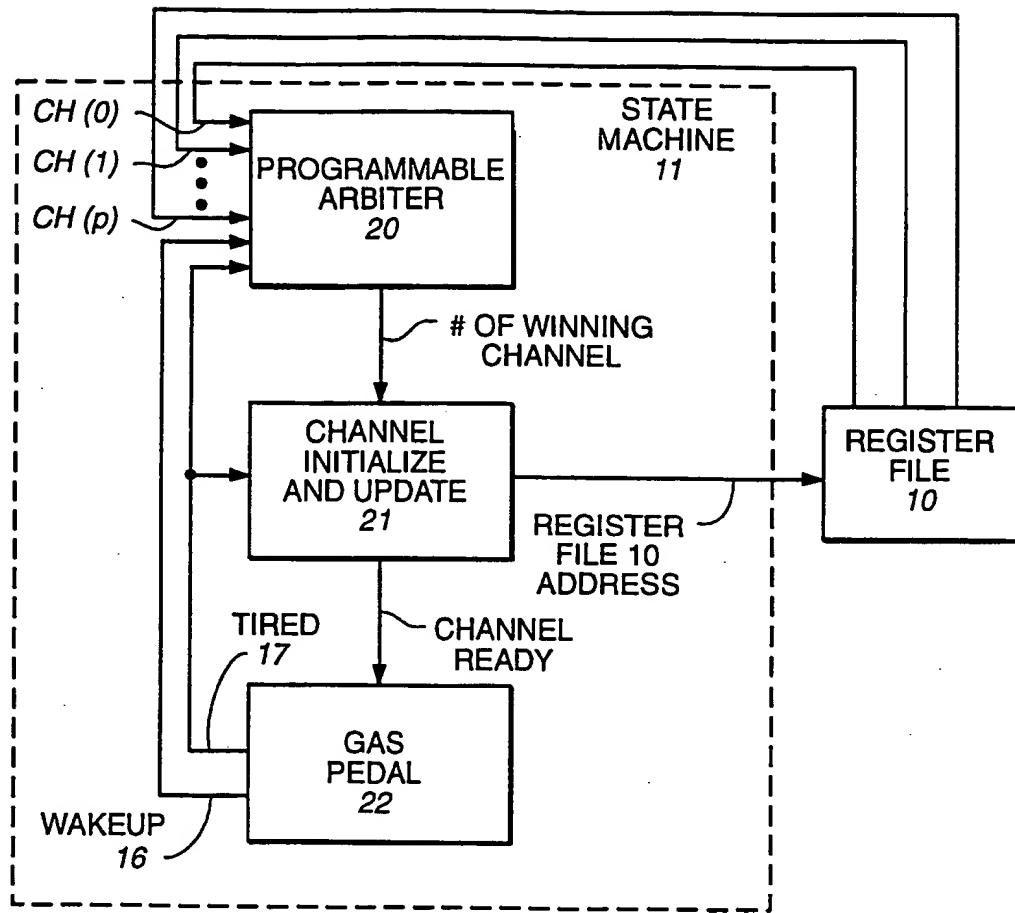
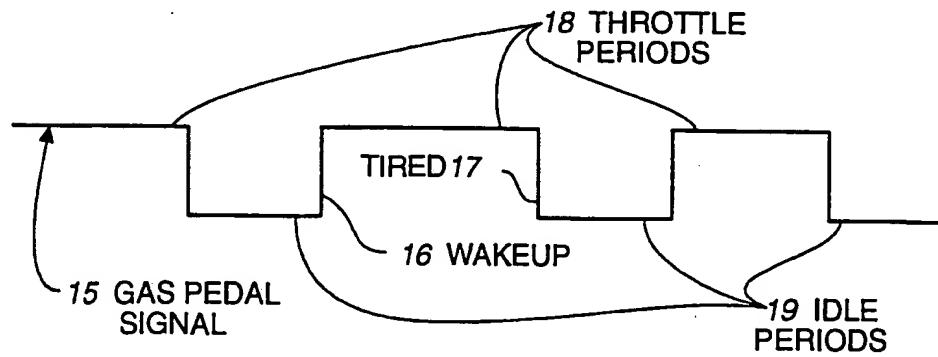


FIG._2
2 / 5
SUBSTITUTE SHEET

**FIG._3****FIG._4**

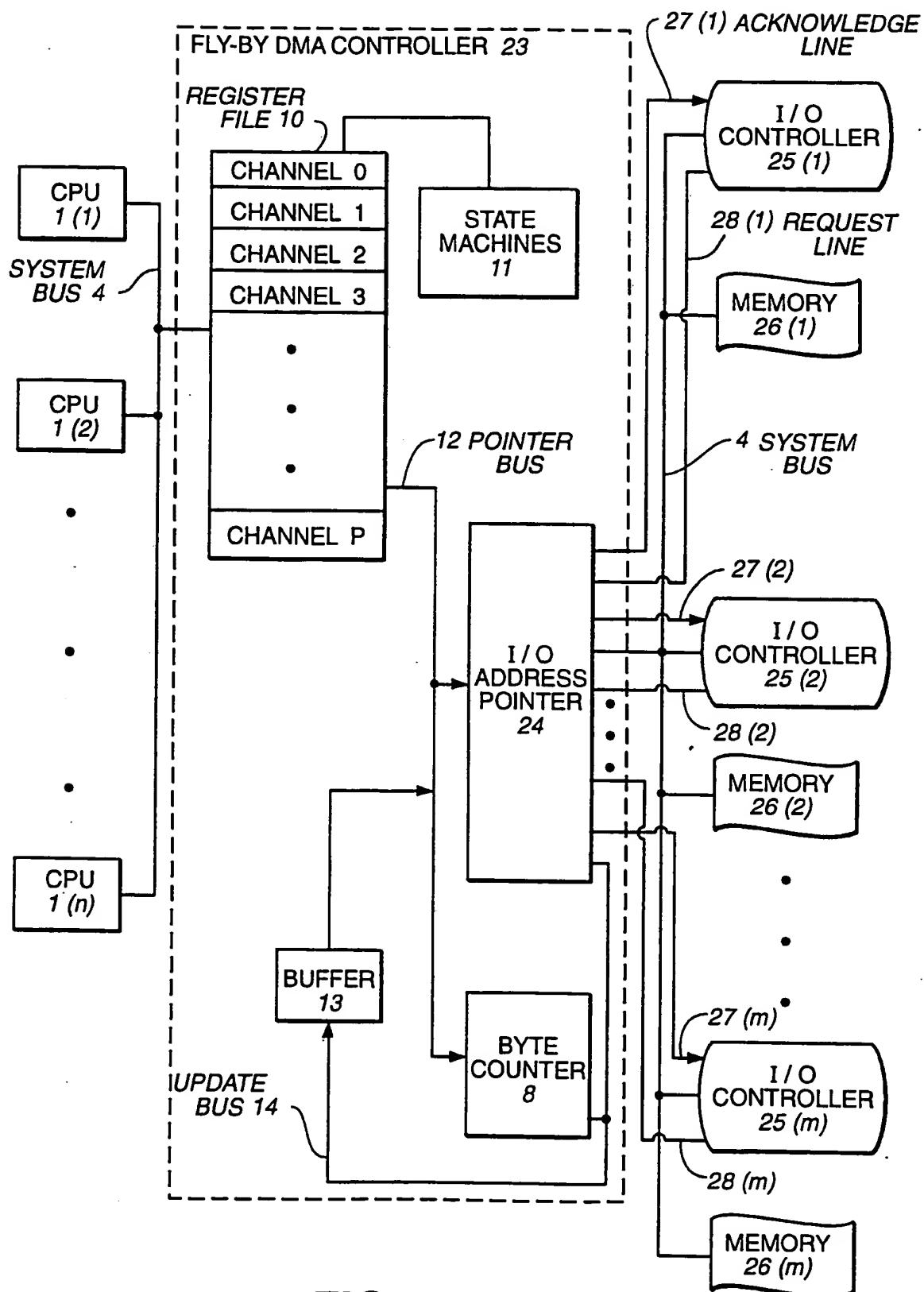
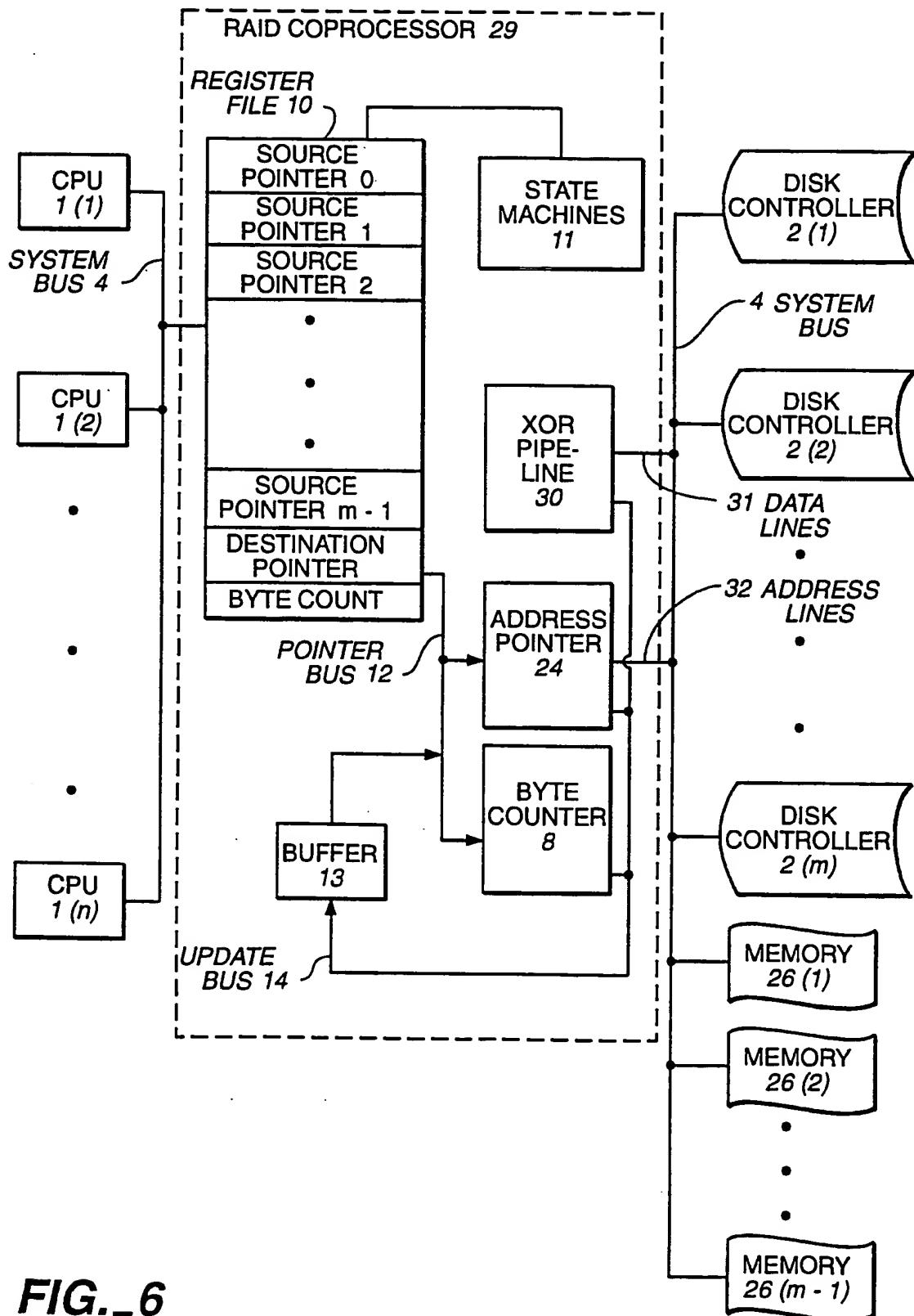


FIG._5
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SUBSTITUTE SHEET

**FIG._6**

INTERNATIONAL SEARCH REPORT

International Application No

PCT/JP 93/00617

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC Int.Cl. 5 G06F13/12; G06F13/28; G06F3/06		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
Int.Cl. 5	G06F	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹		
Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
Y	WO,A,9 111 767 (AUSPEX SYSTEMS, INC.) 8 August 1991 see page 52, line 13 - page 66, line 8; figures 1,15,16 ---	1-3,5-8, 11
Y	EP,A,0 365 116 (HEWLETT-PACKARD LIMITED) 25 April 1990 see page 3, line 46 - page 4, line 41; figures 1-3 ---	1-3,5-8, 11
A	GB,A,2 211 325 (ZIITT) 28 June 1989 see page 1, line 5 - page 3, line 7; figure 1 ---	1-3,8,11 -/-
<p>⁶ Special categories of cited documents :¹⁰</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p>		
IV. CERTIFICATION		
1 Date of the Actual Completion of the International Search 06 SEPTEMBER 1993		Date of Mailing of this International Search Report 10.09.93
International Searching Authority EUROPEAN PATENT OFFICE		Signature of Authorized Officer JONES H.D.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	EP,A,0 482 819 (ARRAY TECHNOLOGY CORPORATION) 29 April 1992 see page 3, column 4, line 6 - page 5, column 8, line 6; figures 1,3 -----	1,4,9,10

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.**

JP 9300617
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 06/09/93

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